

Hot dip galvanizing – Process, applications, properties

Hot dip galvanizing protects steel from corrosion by providing a thick, tough metallic zinc envelope, which completely covers the steel surface and seals it from the corrosive action of its environment. The galvanized coating provides outstanding abrasion resistance. Where there is damage or minor discontinuity in the sealing coat of zinc, protection of the steel is maintained by the cathodic action of the surrounding galvanized coating.

Metallic zinc is strongly resistant to the corrosive action of normal environments and hot dip galvanized coatings therefore provide long-term protection for steel. By contrast, most organic paint coatings used on steel need frequent renewal and when coatings are breached corrosion begins at the exposed area of steel, spreading rapidly beneath the coating film.

The galvanized coating

The galvanizing process produces a durable, abrasion resistant coating of metallic zinc and zinc-iron alloy layers bonded metallurgically to the steel base and completely covering the work piece. No other coating for steel matches galvanizing's unique combination of properties and advantages:

- 1 For most classes of steelwork galvanizing provides the lowest long-term cost. In many cases galvanizing also provides lowest initial cost.
- 2 The galvanized coating becomes part of the steel surface it protects. See 'Metallurgy', page 13.
- 3 The unique metallurgical structure of the galvanized coating provides outstanding toughness and resistance to mechanical damage in transport, erection and service. See 'Abrasion resistance' page 13.
- 4 The galvanized coating is subject to corrosion at a predictably slow rate, between one-seventeenth and one-eightieth that of steel, depending on the environment to which it is exposed. See 'Corrosion rates', page 19.
- 5 Galvanizing's cathodic protection for steel ensures that small areas of the base steel exposed through severe impacts or abrasion are protected from corrosion by the surrounding galvanized coating. See 'Cathodic protection', page 10.
- 6 An inherent advantage of the process is that a standard minimum coating thickness is applied. See 'Coating thickness', page 13.
- 7 During galvanizing the work is completely immersed in molten zinc and the entire surface is coated, even recesses and returns which often cannot be coated using other processes. If required, internal surfaces of vessels and containers can be coated simultaneously. See 'Design', page 33.
- 8 Galvanized coatings are virtually 'self-inspecting' because the reaction between steel and molten zinc in the galvanizing bath does not occur unless the steel surface is

chemically clean. Therefore a galvanized coating which appears sound and continuous **is** sound and continuous. See 'Metallurgy', page 13, and 'Inspection', page 42.

- 9 Galvanizing is a highly versatile process. Items ranging from small fasteners and threaded components, up to massive structural members can be coated. See 'Galvanizing', page 11 and 'Design', page 33.
- 10 The mechanical properties of commonly galvanized steels are not significantly affected by galvanizing. See 'Mechanical properties', page 15.
- 11 Galvanizing provides outstanding corrosion performance in a wide range of environments. See 'Performance', page 19.
- 12 'Duplex' coatings of galvanizing-plus-paint are often the most economic solution to the problem of protecting steel in highly corrosive environments. Such systems provide a synergistic effect in which life of the combined coatings exceeds the total life of the two coatings if they were used alone. See 'Synergistic effect', page 65.

Cathodic protection

Metallic zinc is anodic to steel as indicated by the galvanic series of metals on page 10.

In the presence of an electrolyte, the anodic zinc coating on a galvanized article corrodes preferentially to the cathodic steel basis metal, preventing corrosion of small areas which may be exposed through accidental damage to the coating. The cathodic or sacrificial protection continues for as long as the galvanized coating remains.

A simple description of the phenomenon of corrosion of steel is given on following pages as background for the explanation of cathodic protection.

The nature of corrosion

Corrosion is basically an electrochemical process. It occurs because of differences in electrical potential which exist between dissimilar metals in contact or between small areas on a metal surface in the presence of an electrolyte.

Differences in potential on a metal surface are caused by:

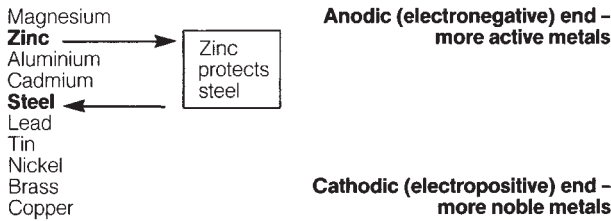
- 1 Variations in composition
- 2 Presence of impurities
- 3 Uneven internal stresses
- 4 A non-uniform environment.

The environment may be a damp atmosphere, surface moisture, or liquid in which the metal is immersed. All serve as electrolytes allowing formation of small electrolytic cells at the metal surface, with resulting corrosion.

Each cell comprises a positive electron-producing anode and a negative cathode. Negatively charged electrons flow from anode to cathode. The loss of electrons converts some atoms of the anode to positively charged ions which in turn react with negatively charged ions in the electrolyte. This reaction between anode and electrolyte causes disintegration and corrosion of the anode metal. There is no corrosion of the cathode metal.

Galvanic series of metals in a sea water electrolyte

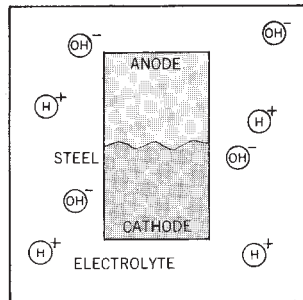
The table below shows a series of metals arranged in order of electrochemical activity in a sea water electrolyte. Metals high in the scale provide cathodic or sacrificial protection to the metals below them. Zinc therefore protects steel.



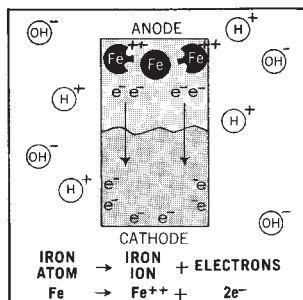
The scale indicates that magnesium, aluminium and cadmium should also protect steel. In most normal applications magnesium is highly reactive and is too rapidly consumed. Aluminium forms a resistant oxide coating and its effectiveness in providing cathodic protection is limited. Cadmium provides the same cathodic protection for steel as zinc but its applications are limited for technical and economic reasons.

Corrosion of steel

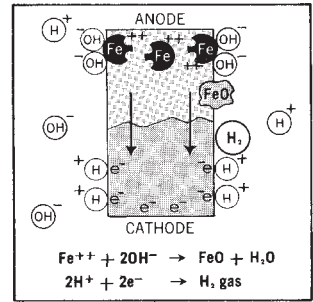
Differences in electrical potential are caused on surface areas of exposed steel by non-uniformity of surface composition, by surface moisture or by the electrolyte in which it is immersed. Small electrolytic cells are formed comprising anodes and cathodes. One such cell is shown diagrammatically.



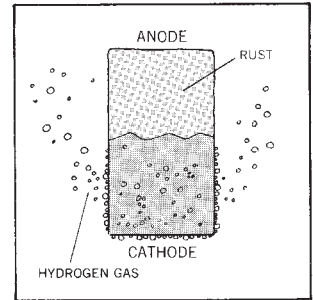
As the result of differences in electrical potential within the cell, negatively charged electrons flow from anode to cathode and iron atoms in the anode area are converted to positively charged iron ions.



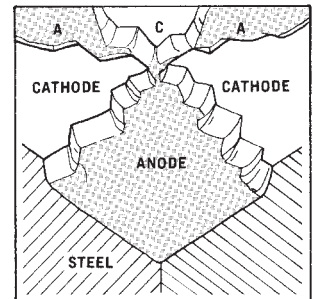
The positively charged iron ions of the anode attract and react with negatively charged hydroxyl ions in the electrolyte to form iron oxide or rust. Negatively charged electrons react at the cathode surface with positively charged hydrogen ions in the electrolyte to form hydrogen gas.



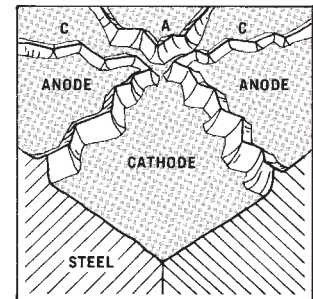
Under suitable conditions corrosion occurs at the rate of billions of complete reactions every second and soon results in a layer of rust appearing over the surface of the anode area.



The anode and cathode areas on a piece of steel are actually microscopic. When greatly magnified the surface might appear as the mosaic of anodes and cathodes visualised here, all electrically connected by the underlying steel. Corrosion occurs in the anode areas.

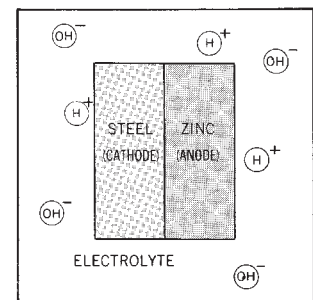


As anode areas corrode new material of different composition and structure is exposed. This results in changes in electrical potentials, causing anodes and cathodes to exchange roles, though not all at once, and areas previously uncorroded are now attacked. These processes may continue until the steel is entirely consumed.

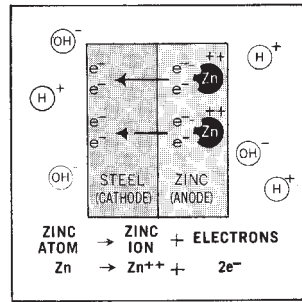


The mechanism of cathodic protection

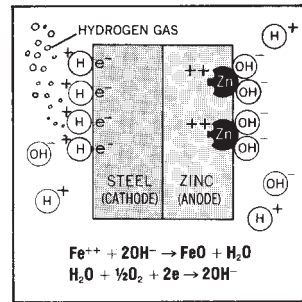
When zinc and steel are in contact in an electrolyte, differences in electrical potential develop and an electrolytic cell is formed. Zinc is more electrochemically active than steel, as shown in the galvanic series above. The zinc therefore becomes the anode for all the steel, preventing the formation of small anodic and cathodic areas on the steel surface.



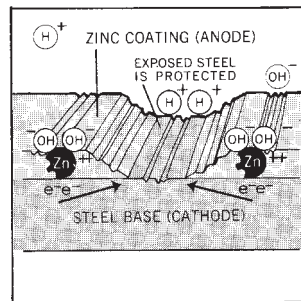
As a result of the differences in electrical potential within the cell, negatively charged electrons flow from the zinc anode to the steel cathode and zinc atoms in the anode are converted to positively charged zinc ions.



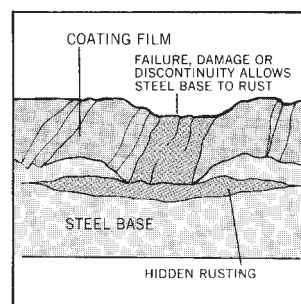
At the cathode surface, negatively charged electrons attract and react with positively charged hydrogen ions from the electrolyte, liberating hydrogen gas. There is no chemical reaction between the steel cathode and the electrolyte. This phenomenon, which prevents corrosion of the cathode, is known as cathodic protection. The positively charged zinc ions at the anode surface react with negatively charged hydroxyl ions from the electrolyte and the zinc is slowly consumed, providing sacrificial protection for the steel.



When discontinuity or damage in the zinc coating exposes the underlying steel, the cathodic protection which zinc provides for steel comes into action and ensures that the exposed steel does not corrode.



Most organic coatings and paint films depend on their sealing ability and in some cases anti-corrosive inhibitive pigments to protect steel from corrosion. They offer little or no protection to bare steel exposed by failure, damage or discontinuity in the coating film. Corrosion starts and spreads rapidly beneath the coating.



The galvanizing process

Metallic zinc coatings are applied to prepared steel surfaces by galvanizing, electroplating, mechanical plating, sherardising, painting with zinc-rich coatings and zinc spraying or metallising. Of these the galvanizing process is by far the most widely used. Galvanizing is normally carried out to AS/NZS 4680 'Hot dip galvanized (zinc) coatings on fabricated ferrous articles'.

Prepared items are galvanized by immersion in molten zinc. The surface of the work is completely covered, producing a uniform coating of zinc and zinc-iron alloy layers whose thickness is determined principally by the mass of the steel being galvanized, as discussed on page 13. This is an important advantage of the galvanizing process – a standard minimum coating thickness is applied automatically.

The molten zinc in the galvanizing bath covers corners, seals edges, seams and rivets, and penetrates recesses to give complete protection to areas which are potential corrosion spots with other coating systems. The galvanized coating is slightly thicker at corners and narrow edges, giving greatly increased protection compared to organic coatings which thin out in these critical areas. Complex shapes and open vessels may be galvanized inside and out in one operation.

Articles ranging in size from small fasteners to structures hundreds of metres high may be protected by the use of modular design techniques. Large galvanizing baths, in conjunction with modular design techniques and double-end dipping allow almost any structure to be galvanized, with greatly reduced maintenance costs and extended service life.

Visual inspection of galvanized products shows that work is completely protected and gives an excellent guide to overall coating quality. (See page 42.)

Preparation of work for galvanizing

Scale, rust, oil, paint and other surface contaminants are carefully removed from the steel by suitable preliminary treatment and subsequent acid cleaning or pickling in sulphuric or hydrochloric acids, followed by rinsing. Iron and steel castings are usually abrasive blast cleaned followed by a brief acid cleaning or they may be cleaned electrolytically to remove foundry sand and surface carbon.

Rolled steel surfaces covered by heavy mill scale may require abrasive blast cleaning prior to acid cleaning.

Fluxing

The acid-cleaned steel article is immersed in a flux solution, usually 30 per cent zinc ammonium chloride with wetting agents, maintained at about 65°C. The flux solution removes the oxide film which forms on the highly reactive steel surface after acid cleaning, and prevents further oxidation before galvanizing. The work is then dried ready for galvanizing.

Alternatively the acid-cleaned article is rinsed and dried, and passed into the galvanizing bath through a layer of molten zinc ammonium chloride flux which floats on the surface of the molten zinc. The molten flux is maintained at 440°C to 460°C, ensuring final cleaning of the steel surface before it contacts the molten zinc.

Galvanizing

On immersion in the galvanizing bath the steel surface is wetted by the molten zinc and reacts to form a series of zinc-iron alloy layers as discussed on page 13. To allow formation of the coating the work remains in the bath until its temperature reaches that of the molten zinc, in the range 445°C to 465°C. The work is then withdrawn at a controlled rate and carries with it an outer layer of molten zinc which solidifies to form the relatively pure outer zinc coating.

The period of immersion in the galvanizing bath varies from several minutes for relatively light articles, up to half an hour or longer for massive structural members.